A TRANSPORTATION AND LOCATION OPTIMIZATION MODEL: MINIMIZING TOTAL COST OF OILSEED CRUSHING FACILITIES IN KANSAS

By

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ABSTRACT

Markets for alternative fuels are emerging and are of great interest to both public and private companies, as well as government agencies looking to differentiate fuel sources to achieve improved and sustainable operational efficiencies. This creates a growing need for innovation and an increased supply of biofuel feedstocks for bioenergy options such as bio-jet fuel.

This thesis aims to assess the logistical feasibility of producing oilseed bio feedstocks and the practicality of building new crush facilities specifically for bio-jet fuel production in Kansas. A logistical optimization model is built by applying data to estimate the potential Kansas supply of rapeseed as a possible feedstock option; transportation and facility costs associated with building; and proposed crushing facility sites, by considering the estimated demand for bio-jet fuel within Kansas.

The developed optimization model determined that even average yields per acre and modest adoption rates by farmers willing to incorporate rapeseed into their crop rotations could provide enough feedstock to supply one or two crushing facilities, depending on a variety of additional factors, including bio-jet fuel demand in Kansas. Sensitivity analysis was performed on key model factors and determined that the most influential factor on both size and number of proposed crushing facilities was the market demand for bio-jet fuel.

Ultimately, further research is required to better understand the actual market demand for bio-jet fuel within Kansas and how competition or supply supplementation of other bio feedstocks can affect the size or number of proposed crushing facilities. There are currently six oilseed crushing facilities operating in Kansas; although all are dedicated to soybean or

sunflower seed. Further studies may find these sites as viable alternative options to building new crushing facilities for a separate type of feedstock.

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CHAPTER I: INTRODUCTION

1.1 Motivation

The need for innovation in the renewable fuels market is increasing, a fact recognized by the United States Military, numerous commercial airlines, freight carriers, and other large companies who are working to advance their supply chains to incorporate bioenergy (Fletcher, US Navy launches Great Green Fleet with 2016 kickoff event 2016). Large companies and government entities alike view alternative fuels as a strong investment in order to capitalize on the strategic advantage of diversifying their fuel options and improving their operational flexibility (Fletcher, US Navy launches Great Green Fleet with 2016 kickoff event 2016).

1.2 Purpose and Objectives

The purpose of this thesis is to assess the logistical feasibility of producing oilseed feedstocks for bio-jet fuel production in Kansas. To meet this goal, the objectives of the thesis are to:

1. Collect data and information concerning transportation and facility costs associated with building and supplying proposed crushing facilities;
2. Analyze the available data to estimate the potential Kansas supply of rapeseed for use as a bioenergy feedstock and conduct related sensitivity analyses; and
3. Assess the practicality of building new crush facilities throughout the state of Kansas for bio-jet fuel production.

1.3 Limitations

The scope of this thesis does not consider the possibility of additional raw materials potentially supplied by the surrounding production areas or the risk of competing with existing crushing facilities within and outside the state of Kansas.

1.4 Framework

The thesis contains the following five chapters: introduction, literature review, data and methods, results, and summary and conclusion. In Chapter I, "Introduction," the thesis objectives and outputs are defined and limitations and framework are discussed. Chapter II, "Literature Review," summarizes and compares previous research on the topic of bio- and renewable energy. Chapter III, "Data and Methods," describes the fundamental aspects of building the optimization model and mathematically defines all parameters, functions and constraints for the empirical model designed. Chapter IV, "Results," reviews and discusses the model runs. Finally, Chapter V, "Summary and Conclusion," summarizes the thesis and proposes further research and improvement of the optimization model.

CHAPTER II: LITERATURE REVIEW

The literature associated with the production, application, and benefits of renewable energy and bio feedstock fuel sources indicate that scholars, scientists, policy makers, reporters, environmental activists, and associated stakeholders have various stances regarding if renewable energy is a feasible option for promoting energy security and decreasing the threat posed by global pollution. This literature review considers various perspectives presented in four subsections and includes the following topics: biofuel production and demand, willingness of farmers to produce bioenergy crops, concerns regarding biofuel production, and interest regarding biofuel production.

2.1 Biofuel Production and Demand

Renewable energy includes the use of biofuels that can be produced from bioenergy crops. According to supply and demand analysis, an increase in the quantity demanded for biofuel produced from biofuel crops requires the production of biofuel feedstocks to increase. The scarcity of fossil fuels and rising environmental concerns will significantly impact the future of renewable energy and biofuel production (FAO 2008).

Biofuels are an alternative energy source to fossil fuels and are derived from biomass such as food and fiber residues, agricultural crops and waste, forestry residues, and others. Biofuels are categorized by their source material and physical state of matter (solid, liquid, or gas). Processed liquid biofuels such as ethanol and biodiesel are primarily produced using agricultural products intended to either replace or supplement traditional fossil fuels. Biodiesel fuels are produced via a transesterification process utilizing oil extracted from bioenergy crops such as soy, rapeseed, sunflower, canola, and other oilseed crops. (FAO, 2008; Giampietro, 1997).

Public scrutiny for environmental contamination coupled with the limited supply of fossil fuels has compelled prominent organizations and lawmakers to enact aggressive policies, minimizing our dependence on non-renewable and environmentally hazardous fuels. These policy changes have and may continue to contribute to growing biofuel demand, subsequently stimulating the production of biofuels (FAO 2008; Schnerpf and Yacobucci 2013).

Numerous European Union (EU) members are working to achieve various renewable energy goals by the year 2020. Sweden, Bulgaria, and Estonia have all managed to reach their renewable energy goals 8 years ahead of schedule. Another 20 countries from the EU are also on track to meet their 2020 renewable energy goals (Kahn and Shahan 2014). Kahn and Shahan (2014) report that the EU increased its use of renewable energy by about 6 percent from 2004 to 2012, suggesting that sourcing 20 percent of all of the EU's energy from renewable sources by 2020 is plausible. Furthermore, the EU has set a new goal of having renewable energy represent at least 27 percent of its total energy needs by 2030 (Kahn and Shahan 2014).

The United States is another developed country promoting bioenergy production to reduce dependence on imported oil for its national energy needs. According to Caldas, et al. (2014), although renewable energy only satisfies 6.6 percent of the nation's current total energy consumption, America's policy makers are actively pursuing multiple regulations and incentives geared towards expanding the availability of inexhaustible energy sources, especially biofuel produced from biomass materials such as crop residues, herbaceous crops, and dedicated energy crops (Caldas, et al. 2014). The Energy Policy Act of 2005 enacted the Renewable Fuel Standard (RFS), establishing minimum biofuel production quotas for the US (Caldas, et al. 2014). In addition, the Advanced Energy Initiative (AEI) of 2006 and 20-in-1 Plan of 2007 were designed to cut US dependence on oil, as well as encourage the advancement of energy biotechnology (Caldas, et al. 2014). Perhaps the most aggressive renewable energy policy is the Energy Independence and Security Act (EISA) of 2007 that is attempting, to increase the supply of advanced biofuels, specifically from cellulosic sources, by 36 billion gallons by the year 2022 (Caldas, et al. 2014). Regardless of the EISA, cellulosic biofuel production has not progressed as expected, perhaps due to the failure of engaging a sufficient number of farmers to dedicate the necessary acres to bioenergy crop production (Caldas, et al. 2014). The Federal Fleet Conservation Requirement (section 142 of the EISA) mandates that the Department of Energy (DOE) require all US federal agencies to reduce their annual petroleum consumption by 20 percent or more and at least half of that must be realized by increasing alternative fuel consumption by October 1, 2015 (Alternative Fuels Data Center 2014).

Specifically in response to the declining availability of fossil fuels and increased public interest in protecting the environment, the Department of the Navy (DoN) aims to utilize renewable fuels to expand its use of alternative and sustainable fuel sources. The DoN established several energy-saving goals, including alternative energy source initiatives aiming to reduce total energy consumption and shore-based energy needs by 50 percent by 2020, as well as the deployment of a Green Strike Group unit dedicated to operating with the use of renewable fuels by the year 2016 (Office of the Secretary of the Navy 2015). To realize these energy goals, the DoN further developed and reinforced all aspects of supply chains needed to produce sustainable sources of hydro treated renewable jet (HRJ) fuels, which includes bio-jet fuels produced using dedicated bioenergy oilseed crops. This enabled the DoN to introduce its Great Green Fleet on January 20, 2016 (Fletcher, US Navy launches Great Green Fleet with 2016 kickoff event 2016).

A Honeywell company, UOP LLC developed the UOP Renewable Jet Fuel Process technology under contract with the United States military. This process is used to produce Honeywell Green Jet Fuel that can be blended with petroleum fuel up to 50 percent without requiring technology or mechanical changes to aircrafts (UOP, LLC 2014). This same renewable jet fuel process is used by AltAir Paramount LLC in California to produce both Honeywell Green Jet Fuel as well as Honeywell green diesel, a direct drop-in substitute for petroleum diesel that can supply the Los Angeles International Airport up to 35 million gallons of fuel per year (Fletcher, United Airlines deploys Honeywell’s green jet fuel at LAX 2016). Fletcher also reports that feedstocks account for about 80 percent of biofuel production costs, which is why Honeywell developed their Renewable Jet Fuel Process technology to take advantage of different types of feedstocks as they become competitively priced (Fletcher, United Airlines deploys Honeywell’s green jet fuel at LAX 2016).

2.2 Willingness of Farmers to Produce Biofuel Feedstocks

While the availability of traditional fossil fuels will decline in the future, it is still unclear if the United States has identified bioenergy crops as a sustainable and holistic or partial substitute to meet long-term energy needs (Pew Research Center 2015). The demand for energy will surely rise relative to the expected increase in the world’s population, therefore the world’s energy supply must be reinforced with viable alternatives to fossil fuels. To better understand the likelihood of increasing the supply of bioenergy crops, researchers have examined the willingness of farmers to produce various crops to serve as biofuel feedstocks.

A farmer's willingness to participate in bioenergy crop production may be affected by multiple factors such as the current market price for diesel fuels, available government subsidiaries, various farm and individual farmer characteristics, regional crop adaptability, and input requirements and expenses for bioenergy crop production such as labor, pesticides, machinery requirements, and contractual arrangements (Jensen 2006, Paulrud and Laitila 2010, Qualls et al. 2011, Bergtold et al. 2014). Current research assessing farmer's willingness to produce bioenergy crops is limited and often exhibits conflicting results, possibly due to regional differences in the population samples of farms and farmers analyzed and the narrow scopes of these studies.

For example, Jensen et al. (2007) found that for surveyed Tennessee farmers, age, net farm income, farm size, livestock ownership, and leased or rented land all displayed a negative impact on the willingness of farmers to produce switchgrass specifically for energy production. Factors such as education level, off-farm income, and farm experience all had a positive correlation on the willingness of surveyed farmers to grow switchgrass for energy production. Furthermore, Jensen et al. (2007) reported that national policy issues such as reducing greenhouse gas emissions and government subsidies did not significantly increase the likelihood of these farmers to dedicate more acres to switchgrass production.

Qualls et. al. (2011) concluded that livestock ownership and land leased or rented had a negative impact on the willingness of farmers in the southeastern United States to produce switchgrass for bioenergy purposes. However, in contrast to Jensen et al. (2007), Qualls et al. (2011) concluded that farm income could play a positive role in increasing switchgrass production. Qualls et al. reported mixed findings for the role that farmer age plays in bioenergy switchgrass production and also mentioned that farmers using no-till conservation practices or own hay equipment are more likely to dedicate more land towards bioenergy switchgrass production. A similar study considered the willingness of Swedish farmers to produce energy crops under different conditions; Swedish production of agricultural biomass primarily consists of willow, cereal grains, rapeseed, and straw (Paulrud and Laitila 2010). Similar to Jensen et al. (2007), Paulrud and Laitila (2010) found farmer age and net farm income to have a negative correlation on farmers' likelihood to produce bioenergy crops.

The availability of contractual arrangements between farmers and bio-refineries and other intermediate processors may also play a significant role in ensuring a reliable supply of biofuel feedstocks. Bergtold, et al (2014) examined the relationship between Kansas farmers' willingness to adopt corn stover, sweet sorghum, and switchgrass under various contractual characteristics. The study found that potential adoption rates varied by region. This was likely due to farmer perception of labor versus other benefits and the expected success of different biomass options in different locations due to water availability, soil quality, and weather. The study also determined that shorter contracts were considered more desirable for all types of feedstocks due to perception of increased flexibility, as well as that the availability of crop insurance and having a bio refinery harvest the feedstock for the farmer also increased the likelihood of farmers' willingness to produce feedstocks (Bergtold et al, 2014).

2.3 Concerns Regarding Biofuel Production

Unfortunately, some researchers believe a rapid increase in demand for biofuel could create transformations within the agricultural market that would be detrimental for both the global environment and economy. For example, a rapid and large-scale increase in bio feedstock production involves utilizing large quantities of crop land, obtained either from deforestation or out-competing land for food crop production. Rapid and sudden deforestation could lead to increased creation of greenhouse gases, while increased biofuel feedstock yields and decreased food crop production may result in inflated food costs (FAO of the United Nations 2008). However, these risks are considered by some researchers to be a necessary cost to ensure future independence from traditional energy production via fossil fuels (Biello 2008). These risks may be mitigated by further advances in biotechnology to achieve improved efficiency of biofuel feedstock production and promotion of in-field conversion practice adoption, such as incorporating biofuel feedstock into crop rotation plans or primarily producing feedstocks on available crop land that would otherwise be left fallow (Biomass Research & Development Initiative 2010).

Giampietro (1997) argues current biofuel technologies cannot decrease the overall environmental impact per unit of net fuel production, citing the growing world population may eventually be more concerned with ensuring adequate food and labor supplies rather than achieving desired environmental improvements related to cleaner energy options.

Likewise, Mendrick (2014), reported that although the UN previously championed biofuels as a desirable alternative to fossil fuels, new evidence is alarming. This evidence suggests the transformation of crops into green energy may actually damage the environment by amplifying global warming (Mendick 2014). Mendrick (2014) further explains the UN is concerned with widespread bioenergy crop cultivation and damages to ecosystems through decreases in biodiversity through deforestation, increases in stress on water supplies, and potential for inflated food prices due to biofuel crop production outcompeting food crop production. Nevertheless, the European Union aims to double their application of biofuels used specifically for transportation from 5 percent to 10 percent by

2020. To help lessen the risk of increasing food costs, the EU will limit the use of food crops for biofuel applications to only 5 percent (Mendick 2014).

Additional research concludes that farming a hectare of forest or native grassland for use in biofuel production can release more carbon into the atmosphere than the benefit gained by using biofuels. This is due to the release of carbon stored in plant roots, shoots, and leaves which stores nearly three times the amount of carbon that is in the world's atmosphere. When considering the carbon that enters the atmosphere after plowing, and deducting the decrease in carbon emissions achieved by application of fossil fuels produced by corn ethanol, it would take 93 years to achieve a net benefit in regards to decreased greenhouse gases (Biello 2008). Similarly, clearing rainforests in other parts of the world for palm oil production would take centuries to repay the resulting carbon debt. For this reason, many researchers advise against clearing forest or grassland for increased biofuel crop production (Biello 2008). Williams suggests that carbon dioxide can be emitted into the atmosphere when native plants and soils are disturbed during land clearing. In some cases, it may involve tens or hundreds of years before bioenergy crops or reclaimed natural vegetation completes the reabsorption and storage of carbon dioxide within soil and plant tissues (Williams 2011).

Biello (2008) notes that diverting food crops to support fuel production within the United States has caused increased production of corn that outcompeted production land for soybeans, resulting in decreased soybean production and increased soy prices within the US. Thus, soybean production was outsourced to Brazil. Increased soybean production in Brazil was made possible by clearing land in the rainforest and savannahs, which released far more carbon emissions than was decreased by the use of corn-based ethanol fuels in the US (Biello 2008).

Studies reported by Biello (2008) do not condemn biofuel production as harmful for the environment, however advantages in carbon emissions are only anticipated when biofuel production uses agricultural land that is either too dry or degraded for food crop and forest growth. Additionally, if the described dry or degraded land is used for biofuel crop production, the crop should ideally be native to the growing area. Another alternative suggested by researchers is to utilize unused agricultural products for biofuel production such as corn stalks, timber waste, and garbage compost, although this tactic would likely accomplish little in regards to an overall decrease in greenhouse gases (Biello 2008).

2.4 Interest in Biofuel Production

Traditional fuel sources including coal, oil, and gas will inevitably expire at some point in the future. Learning to harness the energy sources readily available on Earth, such as bioenergy crops, solar and wind power will ensure a renewable supply of energy without the threat of over-dependence of fossil fuels, foreign energy sources, and more environmentally harmful waste products. Conserve Energy Future (CEF) (2015) believes that turning to renewable energy sources will provide a more affordable and economically reliable energy supply through job creation and reduced maintenance costs. Renewable energy will also provide nations with the opportunity to stabilize energy prices as it would no longer be a finite resource.

The University of Wisconsin-Madison fielded a survey finding that although not all Americans are convinced renewable biofuels can solve our nation’s impending energy needs, sixty-seven percent of respondents exhibited interest in learning more about renewable biofuels. The survey determined that a majority of respondents perceived benefits from biofuels, such as reducing America's dependence on foreign oil and potentially reducing greenhouse gas emissions. The survey also points out that the price of conventional fuels and interest in biofuels are directly related, (University of Wisconsin-Madison 2009). The Pew Research Center found that the American public is displaying an interest in energy policies to develop alternative energy, improved automobile fuel efficiencies, and harsher limits on power plant emissions (Pew Research Center 2015). Survey results from Pew Research reported that 71 percent of participants thought the country, "should do whatever it takes to protect the environment;" however, a similar question indicated that a smaller majority of only 56 percent felt that, "stricter environmental laws and regulations are worth the cost" (Pew Research Center 2015). These findings indicate that although the public is showing interest in renewable bioenergy, it is still uncertain how much people are currently willing to invest in pursuing bioenergy technology.

Although many researchers argue large-scale production of biofuel produced from oilseed crops is not currently a feasible option to replace or even significantly supplement production of fossil-sourced fuels, it is clear the general public and many organizations are interested in pursuing the advancement in biofuel technology to increase both efficiency and long-term reliability of biofuel applications (Giampietro 1997).

2.5 Contribution to the Literature

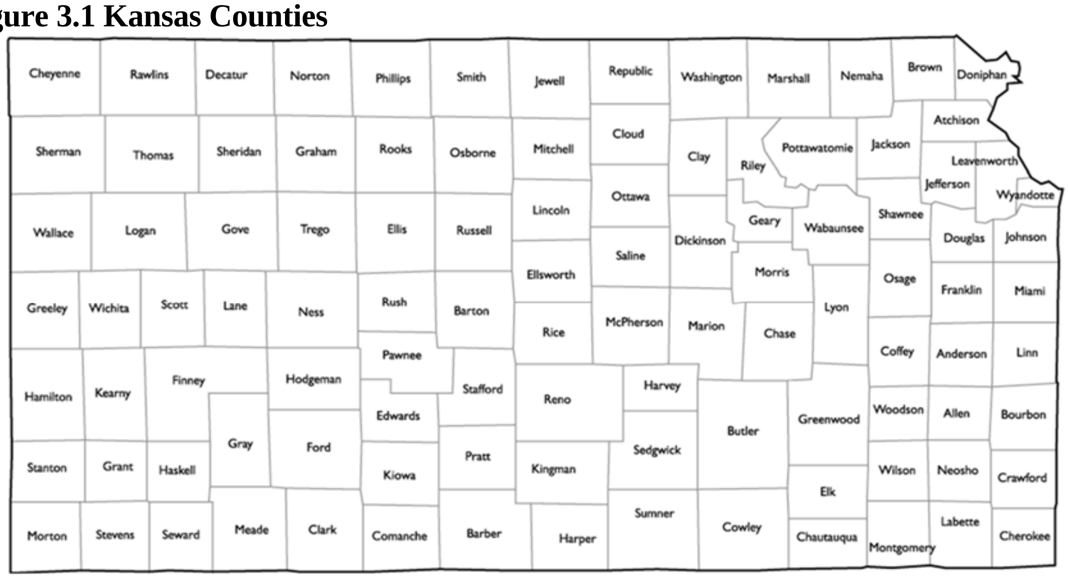
This thesis aims to confirm if rapeseed is a suitable oilseed bioenergy crop to produce within the state of Kansas that can assist in meeting the bio-jet fuel demand posed by the Department of the Navy (DoN) as well as other commercial entities. Applying conservation tillage methods and incorporating bioenergy crops into a crop rotation plan will mitigate the risk of competition with food crops, which displaces food crop production into areas of the globe that require land clearing, releasing higher amounts of carbon into the atmosphere (Biello 2008). By considering both harvested wheat acres in the state of Kansas and farmers' willingness to incorporate oilseeds into wheat production rotations for bioenergy feedstock for the specific purpose of producing bio-jet fuel or biodiesel, an optimization model can be applied to determine if (1) there is a feasible need to build crushing and processing facilities and (2) the optimal location(s) for a crushing and processing facility within the state of Kansas.

CHAPTER III: DATA AND METHODS

To determine optimal locations for crushing and processing facilities within the state of Kansas for an oilseed bioenergy crop, the transportation plus facility cost for each location must be minimized while meeting defined constraints. In this chapter, the objective is to minimize the total cost of building a potential facility, as well as the transportation cost associated with supplying that facility. This objective is analyzed and transformed into a mathematical programming model to be optimized.

Figure 3.1 provides a map of all 105 county locations in the state of Kansas. Each county has a given level of raw material to supply and each county is also a potential location for a small, medium, or large sized crushing facility with a maximum level of demand.

Figure 3.1 Kansas Counties



The goal of the mathematical programming model designed is to determine the optimal county facility location(s) by minimizing facility and transportation costs, subject to supply and demand constraints.

3.1 Decision Variables

This location optimization model determines the optimal county locations in which to build crushers to produce raw oil for conversion to bio-jet fuel and the size of those respective facilities. The counties determined to be locations to support new crushing facilities will receive truckloads of raw materials from other counties; therefore the first set of decision variables represent the location(s) a facility should be built, as well as the size of the facility best suited to process the incoming supply of raw material. The other decision variables represent the amount of oilseeds or feedstock that is shipped from counties growing the feedstocks to the respective facilities. Specifically, the decision variables are defined as follows:

- x_{ij}= the amount of raw material, measured in truckloads (1 truckload = 26 tons), shipped to a proposed facility location, j, that was produced in a given county, i
- B_{jk}= where B is a binary variable to build (1) or not build (0) a facility in a given county, j (j=1…105), and k represents the size of the proposed facility to build: small (1), medium (2), or large (3).

Note that there are 105 counties in the state of Kansas, therefore this model has 11,025 variables representing transport of raw material (x_{ij}), as well as 3 binary decision variables (representing a small, medium, or large-sized facility) for each county representing crushing facility construction, providing 315 binary decision variables (B_{jk}).

3.2 Objective Function

The objective of this model is to find the ideal facility location(s) within the state of Kansas that minimizes the sum of building a new facility plus the transportation cost incurred from shipping product to the new facilities. Consider the shipment of raw materials in truckloads from county i to a facility built in county j; the transportation cost per truckload is given by c_{ij} and the size of each shipment is x_{ij}. The cost function is assumed linear, therefore the total transportation cost between county i and j is defined as $c_{ij}x_{ij}$. The sum over all counties, i, shipping to any county containing a crushing facility, j, provides the overall transportation cost of shipping the feedstock.

Additionally, the cost of building all proposed facilities must be considered. Recall that B_{jk} is a binary variable used to determine if building a facility is optimal for a given county, j, and k designates if a small, medium, or large sized facility is built in a given county. F_{jk} is the facility cost for building a small, medium, or large sized facility (denoted by k), in a given county, j.

Therefore the objective function for the model is to:

$$\text{Minimize } (\sum_{i=1...105}\sum_{j=1...105} c_{ij}x_{ij}) + (\sum_{j=1,...,105}\sum_{k=1,2,3} F_{jk}B_{jk})$$

The objective function minimizes the total facility costs for proposed crushing sites and transportation costs to supply those facilities.

3.3 Defining the Constraints

To minimize the objective function defined above, the optimal values for the decision variables must be determined without violating the model's constraints. The constraints are a function of the decision variables and ensure the final results are feasible and meet required production limitations. Consider the total outgoing truckloads of raw material produced in county i which are being shipped to county j, denoted by x_{ij}. These shipments cannot exceed the total number of raw material truckloads produced in county i, denoted as a_i. Therefore, each county must ship less than or equal to the same number of truckloads produced within that county.

Next, consider the total incoming truckloads of raw material into county j. If the model proposes to build a new facility, then for any given county, the sum of these shipments must be greater than or equal to a minimum level of demand defined in the model. The maximum demand for a crusher facility of size *k* is given by d_k. The minimum level of demand represents the needed demand to make a facility operational. That is, this constraint ensures that a minimum plant capacity will be satisfied in order to sustain production and justify building a new facility. Thus, total shipments into a county with a crusher of size *k* must be less than d_k but greater than md_k, where *m* is the proportion indicating the minimum operational demand needed by the facility (e.g. 70 percent).

A total demand constraint is included, as well. This constraint is directly linked to the total truckloads of raw material available across the entire state. This constraint states that the total capacity of crushing facilities must be greater than or equal to a minimum level of demand for the market. This demand constraint ensures that a total minimum demand is met to warrant the viability of an oilseed market for bio-jet fuel in Kansas. This demand, denoted by *TD*, is the minimum demand required to sustain the market and is theoretical. Sensitivity analysis is performed on this constraint to measure the potential effect if market demand for bio-jet fuel were to increase or decrease in the state of Kansas.

Furthermore, only one small, medium, or large facility is allowed to be built in each county. This constraint ensures that multiple facilities of different sizes will not be built within the same county.

The final constraint ensures the continuous variables are non-negative. This non-negativity constraint ensures that the model will not attempt to optimize the objective function by shipping less than zero total truckloads of raw material.

The constraints detailed above can be written mathematically as follows:

- $\sum_{j=1,\ldots,105} x_{ij} \leq a_i$ for i=1,…,105;

- $\sum_{i=1,\ldots,105} x_{ij} \geq m(\sum_{k=1,2,3} d_k B_{jk})$ for $j = 1,.., 105$;
- $\sum_{i=1,\ldots,105} x_{ij} \geq \sum_{k=1,2,3} d_k B_{jk}$ for $j = 1,.., 105$;
- $\sum_{j=1,\ldots,105} \sum_{k=1,2,3} T_k B_{jk} \geq TD$, where T_k is the truckloads required per plant to meet their capacity for plant size k;
- $\sum_{k=1,2,3} B_{jk} = 1$ for $j=1,\ldots,105$;
- $x_{ij} \geq 0$ for $i = 1,..,105$ and $j = 1,\ldots,105$;
- B_{jk} are binary for $j = 1,\ldots, 105$ and $k = 1, 2, 3$.

The above constraints will define the feasible region for the model and ensure the model achieves a strategic and practical solution regarding crushing facility placement(s) in terms of minimizing both facility and transportation costs.

3.4 Spreadsheet Model and Open Solver

The described model was constructed using Microsoft Excel 2013 and solved using linear optimizer called Open Solver. This open source optimization solver for Microsoft Excel is developed by Frontline Systems and can manage massive amounts of data and variables to quickly solve both linear, integer, and non-linear problems (Mason 2012).

Appendix A summarizes the Microsoft Excel version of the model. The first tab comprises the working model; the decision variables, constraints, and the objective cell are color coded blue, red, and dark green respectively. The remaining tabs include the data necessary to calculate the estimated raw material supply and transportation costs associated with shipping available product to crushing facilities.

3.5 Data and Parameters

Recall that this thesis must consider the harvested wheat acres in the state of Kansas and farmers' willingness to incorporate oilseeds into wheat crop rotations for bioenergy feedstocks, specifically for bio-jet fuel or biodiesel applications. The potential supply of raw material in each county (a_i) was estimated by determining the number of wheat acres farmed per Kansas county from the USDA-NASS Quick Stats tool on their website (United States Department of Agriculture n.d.). This model utilized the most recent complete data available, which reported the number of wheat acres farmed during 2007. The estimated adoption rate of farmers willing to incorporate rapeseed every three years into a winter wheat rotation plan was assumed to be 20 percent (Andrango, et al. 2014) . To estimate the number of dedicated acres for a bio-feedstock, the number of harvested wheat acres per county was divided by 3 (given it is common for oilseeds to only be incorporated into wheat (or other small grains) rotations every three years) and multiplied by 20 percent (estimated bioenergy feedstock adoption rate).

The demand constraint representing the total market demand for oil in Kansas is theoretical. The estimated Kansas consumption of jet fuel is 10.1 trillion BTUs, based off of Kansas Energy Consumption Estimates of jet fuel in 2013 (U.S. Energy Information Administration 2013). According to the International Air Transport Association (IATA), up to 50% of conventional jet fuel can be blended with bio-jet fuel (International Air Transport Association 2015); therefore, the Kansas demand for bio-jet fuel can be estimated at 5 trillion BTUs. Consistent with Energy Skeptic, 1 gallon of heating oil, diesel fuel, or jet fuel is equal to 149,000 BTUs (Energy Skeptic 2013), which equates to about 3.36 billion gallons of demanded bio-jet fuel in the state of Kansas alone. Using a transesterification process, one ton of finished oil could be used to produce about 300 gallons of biodiesel (Milbrandt, Kinchin and McCormick 2013), therefore it is assumed that the demand for finished oil from bio feedstocks in Kansas to equal roughly 11.2 million tons (or 430,769 truckloads of raw material). This model conservatively assumes an upper limit on the demand (*TD*) for the raw material to produce bio-jet fuel of 275,000 truckloads of raw materials. Sensitivity analysis is conducted to assess lower levels of demand, as well.

The distance in miles between each county centroid was calculated using GIS software and the distance between each county was multiplied by \$2.33, which represents the 5-year average cost per mile to ship a full truckload of grain in the state of Kansas according to Jared Flinn, Operating Partner for Bulkloads.com on January 26th, 2016. This provided the data for the objective function coefficients in the model to calculate transportation costs (c_{ij}).

The remaining parameters of the model include the sizes of each crushing facility (d_k) and the number of truckloads to meet this demand (T_k). The size of proposed crush facilities is defined by the average crush capacity per day; a small, medium, and large sized soybean facility is 500, 900, and 1,500 tons per day, respectively (Shumaker, et al. 2000). These daily capacities were multiplied by 325, the estimated number of operating days per year and divided by 26, the number of tons per truckload (Bulk Loads, LLC 2016) to determine each plant capacity for each plant size in truckloads per year.

Some parameters values are subject to sensitivity analysis, which is discussed further in section 3.6 Sensitivity Analysis.

3.6 Sensitivity Analysis

Sensitivity analysis was performed using the model to assess the impact on the model to changes in the model parameters. Recall, a number of the model parameters were assumed (e.g. adoption rate and total market demand). It would be of interest to see what happens if these assumptions change to assess the dynamics of this market from the farm to the crusher. The model was applied to the following scenarios to assess the robustness and impact on the optimal solution to the model.

Table 3.1 Sensitivity Analysis Model Runs

Model	Adoption Rate	Yield/Acre	Min. Production Capacity	Demand
A- Base	**20%**	**3,450**	**70%**	**38,000**
B	10%	1,900	70%	10,000
C	10%	1,900	70%	5,000
D	10%	1,900	80%	10,000
E	10%	1,900	80%	5,000
F	10%	3,450	70%	19,000
G	10%	3,450	70%	9,500
H	10%	3,450	80%	19,000
I	10%	3,450	80%	9,500
J	10%	4,800	70%	26,000
K	10%	4,800	70%	13,000
L	10%	4,800	80%	26,000
M	10%	4,800	80%	13,000
N	20%	1,900	70%	20,000
O	20%	1,900	70%	10,000
P	20%	1,900	80%	20,000
Q	20%	1,900	80%	10,000
R	20%	3,450	70%	19,000
S	20%	3,450	80%	38,000
T	20%	3,450	80%	19,000
U	20%	4,800	70%	50,000
V	20%	4,800	70%	25,000
W	20%	4,800	80%	50,000
X	20%	4,800	80%	25,000
Y	30%	1,900	80%	30,000
Z	30%	1,900	80%	15,000
ZA	30%	3,450	80%	55,000
ZB	30%	3,450	80%	27,500
ZC	30%	4,800	80%	79,000
ZD	30%	4,800	80%	39,500
ZE	30%	4,800	80%	10,000

CHAPTER IV: RESULTS

This chapter presents the results from the model runs and sensitivity analyses. Section 4.1 describes the optimization model solution for model A and section 4.2 discusses sensitivity analyses.

4.1 Baseline Results

The base model (A) was run with the following parameter values: 20 percent expected adoption rate, an average yield of 3,450 pounds of rapeseed per acre, 70 percent minimum required production capacity per facility built, and a total demand of 38,000 total truckloads of rapeseed.

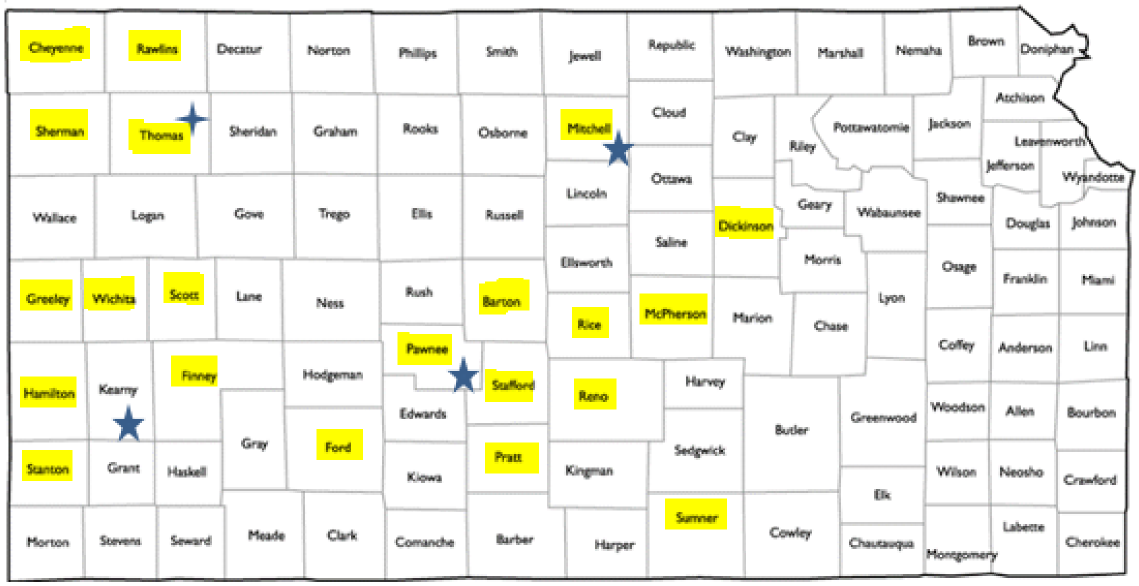
Open Solver provided the following LP optimal solution for the baseline model as shown in Table 4.1.

Table 4.1 Baseline Model Optimal Solution

Model	Adoption Rate	Yield/Acre	Min. Production Capacity	Demand		Model	Total Cost	Small	Medium	Large
A- Base	20%	3,450	70%	38,000		A-Base	$ 143,443,834.91	1	3	0

The names of counties contributing more than 600 potential truckloads of rapeseed per year are highlighted in yellow and facility locations are designated with a star in Figure 4.1 (five-point stars represent a medium sized facility and a four-point star represents a small facility):

Figure 4.1 Model A Facility Locations



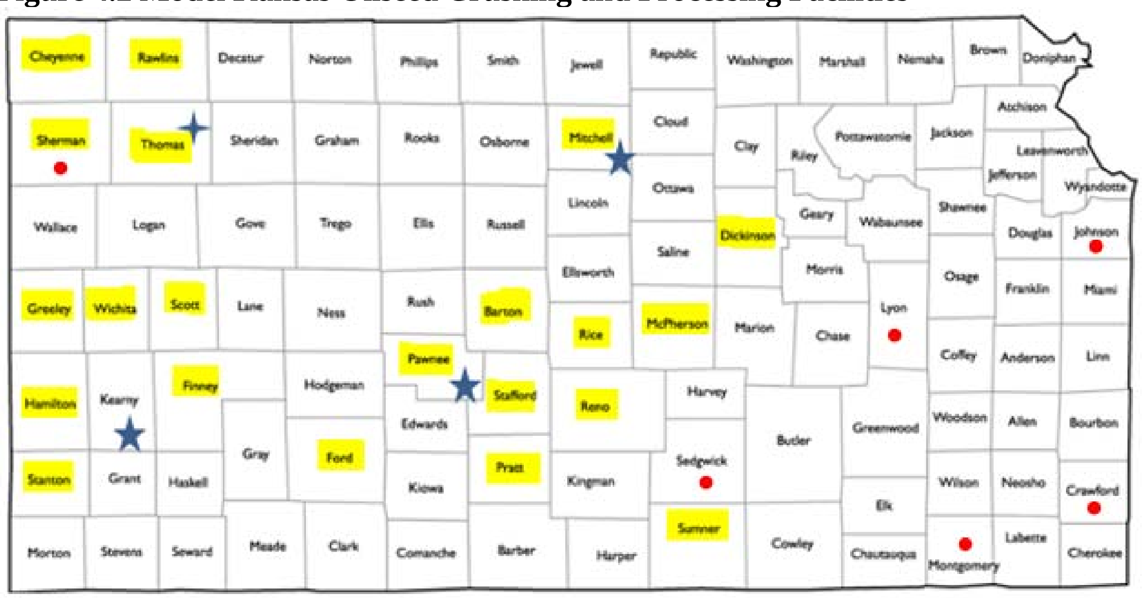
The values used for expected adoption rate and average yield per acre are the most realistic in terms of real-life application of the model. Note that a poor harvest and/or decreased farmer adoption rate for rapeseed will decrease raw material supply.

The demand value of 38,000 truckloads is nearly equal to the 38,038 total truckloads of raw material available across Kansas under the assumptions of a 20 percent adoption rate and average yield of 3,450 pounds per acre. This demand value allows the model to solve the objective function such that 38,000 or more truckloads of raw material can be processed by the facilities built. Model A satisfied the demand constraint by solving for one small facility and three medium facilities, thereby requiring a total production capacity value equal to 38,000 annual truckloads of rapeseed.

Although the combined total production capacity of the four facilities built is equal to 40,000 truckloads per year, only 28,000 truckloads of feedstock are shipped to crush sites. This is the result of requiring only 70 percent minimum production capacity to justify building each facility. If this constraint value was increased to 95 percent, then the full demanded value of 38,000 truckloads will be shipped, however there would be no change in the number or size of facilities built.

The model determined that Mitchel, Pawnee, and Kearny counties are suitable locations for medium crushing facilities and Thomas county is suitable for a small crushing facility. Considering the locations of the highest wheat-producing counties, the proposed facility locations seem appropriate in terms of minimizing the distance raw materials must travel to reach the crushing sites. However, it is imperative to note the locations of existing oilseed crush facilities currently operating in Kansas. See Figure 4.2 for existing facilities denoted in red (Soyatech, LLC 2011).

Figure 4.2 Model Kansas Oilseed Crushing and Processing Facilities



The existing Kansas oilseed crush facility locations depicted above are all dedicated to soybean or sunflower seed and are not currently processing canola or rapeseed. Although it is important to consider if these locations would contribute to the Kansas bioenergy supply (or could compete in the bioenergy space in the future). This issue is not within the scope of this thesis.

4.2 Sensitivity Analyses

The results for each model run defined for the sensitivity analyses in section 3.6 are described in Table 4.2.

Table 4.2 Sensitivity Analysis Model Results

Model	Total Cost	Small	Medium	Large	Demand
A-Base	**$ 143,443,834.91**	**1**	**3**	**0**	38000
B	$ 60,473,608.38	0	1	0	10000
C	$ 31,250,776.50	1	0	0	5000
D	$ 69,871,819.56	0	1	0	10000
E	$ 34,832,631.13	1	0	0	5000
F	$ 98,677,557.48	0	2	0	19000
G	$ 48,318,621.34	0	1	0	9500
H	$ 114,118,220.01	0	2	0	19000
I	$ 54,726,917.22	0	1	0	9500
J	$ 114,953,393.69	1	2	0	26000
K	$ 69,021,053.06	1	1	0	13000
L	$ 130,556,334.21	1	2	0	26000
M	$ 76,599,459.07	1	1	0	13000
N	$ 95,486,346.10	0	2	0	20000
O	$ 46,973,644.96	0	1	0	10000
P	$ 108,389,514.40	0	2	0	20000
Q	$ 52,875,204.64	0	1	0	10000
R	$ 79,775,527.55	0	2	0	19000
S	$ 160,224,948.59	1	3	0	38000
T	$ 88,857,485.12	0	2	0	19000
U	$ 167,175,867.10	1	4	0	50000
V	$ 87,073,997.93	4	0	0	25000
W	$ 184,853,645.59	1	4	0	50000
X	$ 92,898,948.98	4	0	0	25000
Y	$ 125,991,276.49	3	1	0	30000
Z	$ 72,798,212.12	1	1	0	15000
ZA	$ 198,359,803.53	0	5	0	55000
ZB	$ 100,121,205.63	1	2	0	27500
ZC	$ 265,762,265.46	2	6	0	79000
ZD	$ 217,695,661.99	5	3	0	39500
ZE	$ 34,732,022.90	0	1	0	10000

Recall that the right hand side of the market demand constraint value, listed in the last column of Tables 3.1 and 4.2, is directly linked to the total truckloads of raw material needed to meet facility capacities, which is tied to the supply constraints. Therefore, as the estimated adoption rate and yield per acre values are increased/decreased, the value for demand must be increased/decreased, respectively, in order to meet the market demand. To understand the effect of the minimum market demand, each adoption rate and yield per acre combination was run with a large demand value (nearly equal to the total number of available raw material truckloads for Kansas) and a smaller demand value. As seen in the above Table 4.2, as market demand (*TD*) decreased, the number and/or size of facilities built decreased, as well. This positive correlation between the demand value and the number and/or size of proposed facilities indicates that as the raw material demand is decreased, the model may optimize the objective function such that less truckloads are transported than what is actually available; this is due to a lack of demand for a finished product.

In general, as the estimated adoption rate and yield per acre increased, the number and size of facilities built also increased. This positive relationship is expected between the amount of available raw material supply and the number and size of facilities because as available supply increases, so must the production capacity to process the raw material, when sufficient market demand is present. The exception to this relationship is when the supply increases, but the demand substantially decreases as seen in model runs F and ZE as seen in Table 4.3.

Table 4.3 Model Runs: H and ZE Results

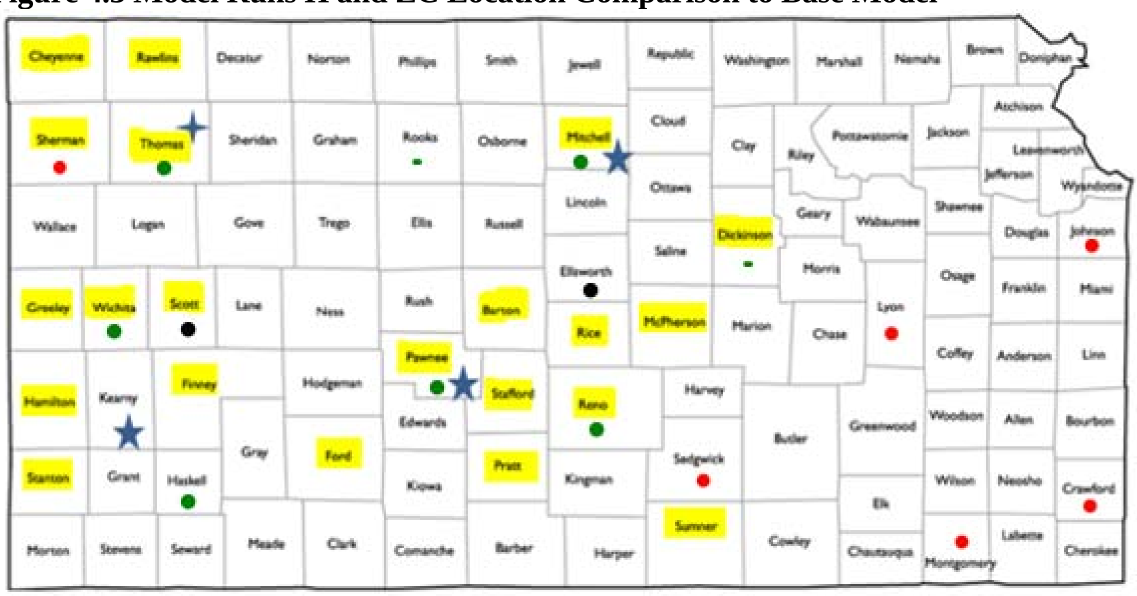
Model	Adoption Rate	Yield/Acre	Min. Production Capacity	Demand		Model	Total Cost	Small	Medium	Large
H	10%	3,450	80%	19,000		H	$ 114,118,220.01	0	2	0
ZE	30%	4,800	80%	10,000		ZE	$ 34,732,022.90	0	1	0

Although both the adoption rate and yield per acre parameters were increased in model run ZE, effectively increasing the total supply of raw material from 19,019 truckloads to 79,385 truckloads of rapeseed, the number of facilities built decreased by half; this is due to the strong positive relationship between the demand value and the number of facilities built.

Table 4.2 also indicates that increasing the minimum required plant capacity value from 70 percent to 80 percent had no effect on the number or size of proposed facilities built. The sensitivity analysis concludes that although each of the parameters tested can have a significant impact on the final outcome of the model, the demand value exhibits the strongest influence of all analyzed parameters. Therefore, an accurate market demand value is critical to achieving a reliable solution.

Figure 4.3 illustrates how changes in the adoption rate, yield per acre, and demand can change the optimal location for crushing facilities as compared to the baseline model, A. Model ZC solved for six medium-sized facilities and one small facility (marked in green) and Model H solved for two medium-sized facilities in both Ellsworth and Scott counties (marked in black).

Figure 4.3 Model Runs H and ZC Location Comparison to Base Model



Note that Model ZC proposed facilities for Thomas, Mitchel, and Pawnee counties, which is mostly aligned with results from the baseline model A. Overall, most model runs completed for the sensitivity analysis yielded proposed facility locations in the same general areas, including West and Central Kansas. This could vary if the type of feedstock is changed from rapeseed to soybean or sunflower seed, in which case one could expect proposed facility locations to shift east towards existing facilities (marked in red) or decrease to zero (if the currently operating crushers for soybean and sunflower can process additional demand).

CHAPTER V: SUMMARY AND CONCLUSIONS

As defined in Chapter 1, the purpose of this thesis was to assess the logistical feasibility of producing oilseed feedstocks for bio-jet fuel production in Kansas and to develop a logistical optimization model to assess the feasibility of this goal. Sensitivity analysis was also completed to assess the robustness of the model and to identity particularly favorable or undesirable scenarios that could strongly influence the optimal solution of the model.

Strictly considering the available data and information applied in the model, it is evident that Kansas could successfully support 70 percent production requirements of multiple rapeseed crushing facilities under the following assumptions: a 10-20 percent adoption rate by wheat farmers willing to incorporate rapeseed into their wheat crop rotation and an average yield of 3,450 pounds of rapeseed per acre planted. The model also found that Kansas could support a single small or medium sized facility with as little as a 10 percent adoption rate and a below-average yield of 1900 pounds of rapeseed per acre planted.

Sensitivity analysis found that although the amount of raw material available is an important characteristic in determining the facility size required at a given location, the estimated market demand value for biodiesel was found to have the largest impact on facility size. This finding emphasizes the importance of accurately gauging the market opportunity available for raw pressed oil in a bioenergy application.

Future research should apply current wheat farming data and investigate if the proposed facility locations are capable of sustaining an industrial crushing facility; this will improve the validity of model solutions. Furthermore, it is advised to further explore the market for raw, pressed oil within the bioenergy space in order to improve the model's effectiveness in terms of the demand constraint, *TD*. Additional types of bio feedstock should be assessed to determine feasibility in terms of bioenergy applications, namely soybean and sunflower seeds due to the crushing facilities already operating in Kansas (Soyatech, LLC 2011). Prospective investors, researchers, and government agencies could use this thesis as a starting point in determining the next steps required to better position Kansas as a contributor to the renewable fuels market by considering the most likely locations capable of producing biofeedstock sources.

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APPENDIX A: SUPPLEMENTARY BASELINE MODEL A FILE